Review of the History of Concepts about Vacuum Space

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Abstract

This paper reviewed the history of sequential advances of the physical concepts regarding the vacuum space in different ages. There are three widely divergent physical concepts about the vacuum space; the first one of which is based on the old classical physics that the vacuum space is absolutely empty space while the second is the transition thought that this space is filled up with some unknown material called ether. However, the lack of concrete investigational support, leads to the discard of these two hypothetical concepts. On the contrary, according to the new concept, vacuum space is neither completely empty nor filled with ether but supports some soft activities taking place in it at nano-scale, which is called quantum vacuum space. Brief history of different concepts about vacuum space, since its discovery to date has been discussed in this paper.

Keywords

Vacuum Space; Classical Physics; Quantum Physics; Nano-scale Activities

Introduction

This review discussed the motivation of the work that why the concept of "vacuum" is interesting to physicists and how the progress in understanding the "vacuum" has helped the modern physics. Concisely, the extensive expedition of the history of concepts about vacuum space in four centuries was briefly illustrated in this review, to properly realize its realistic perception in this age of sophistication. Revealing of various soft activities taking place in this quantum vacuum space has significantly amplified its importance.

This paper was organized as follows: section-2 reveals the starting history of vacuum space, purely based on classical physics, section-3 describes the consequence of "ether" idea and the efforts of the scientists to confirm this idea devoid of any amenable results, section-4 enlightens the new sphere of activity of the modern quantum physics by considering various parameters, clarifying the novel concepts about vacuum space. Finally section-5 briefly describes about some categories of vacuum applications.

Starting History

The history of vacuum was very interesting. In the 17^{th} century Otto Von Guericke, a scientist and mayor of Magdeburg (Germany), was the inventor of the "nothing" we now call "vacuum". He defined the vacuum as "space having nothing in it". This discovery was a shocking one, because Aristotle denied the existence of vacuum: "vacuum is nothingness, and nothingness does not exist" as well "vacuum is a logical impossibility" [Middleton (1964)]. Consequently, it was concluded that empty space (vacuum) is intrinsically impossible and cannot exist. Then to prove the existence of vacuum, in 1663 Guericke demonstrated the power of a vacuum with his Magdeburg Hemispheres to Emperor Ferdinand III. Subsequently after the justification of the existence of vacuum from this experiment, the issue about the existence of vacuum was more or less resolved. At this stage the concept of vacuum space was based on old hypothesis of emptiness followed by the ether supposition, both established on classical physics, without replying a lot of interrogations. Therefore, due to the lack of essential knowledge, classical physics was the only preference at that time.

Vacuum in Classical Physics

Ether Hypothesis

In the 18^{th} century physicists suggested a hypothesis that the space is filled with an unknown substance called the "ether"; and then it was assumed that vacuum space also has this ether medium. This idea was related with classical physics because waves have to propagate in some medium. The "ether" idea was not widely accepted as a hypothesis, with its controversies: for "ether" to exist, it must have some very unusual properties like it has to be a totally

transparent medium and must be perfectly frictionless while on the same time it cannot propagate mechanical waves. In reality, it is very problematic just to imagine such material. Therefore ether was never formally accepted as a true physics concept. This idea went back and forth through the centuries until finally codified by Maxwell's theory of the luminiferous ether. In the 19th century, the Michelson-Morley designed an experiment [Fowler (2008)] to detect the ether's effect on the speed of light and ultimately to discover whether the earth's speed relative to the ether could be detected.

Michelson-Morley Experiment

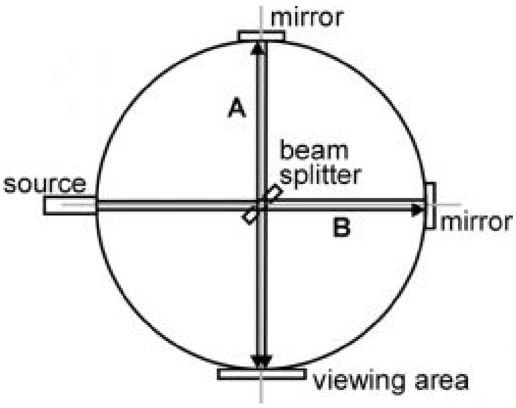

FIG. 1: MICHELSON-MORLEY INTERFEROMETER

The Michelson-Moreley experiment was undertaken in 1887 to detect the existence of hypothetical "ether". The device used in his experiment termed as an interferometer is illustrated in Figure-1. A beam of light is emitted from the source. This light beam hits a beam splitter which divided into two. One beam is reflected upward along arm A to a mirror which reflects it back to the beam splitter. The other beam is transmitted through the beam splitter along arm B to a mirror which reflects it back to the beam splitter as depicted in the diagram. Both reflected beams are then combined by the beam splitter and travel down to a viewing area. It was reasoned that if the speed of light is affected by the presence of the "ether", then the time taken by the light to travel with-and-against the earth's movement through the "ether" would be greater than the time for the light to go at right angles to that direction. For the analysis of time delay between the arrivals of two half-pulses of light, let c denote the speed of light in miles per second relative to the ether and v is the rate of the ether flow in same units. If d is the upstream distance travelled by ether, then the resultant time taken will be $d/(c-v)$ seconds and the time to come back will be $d/(c+v)$ seconds. The typical derivations of "upstream and downstream round-trip time" and "cross-stream round-trip time" according to figure-1 are given as follows:

$$\text{Upstream \& downstream round-trip time} = 2dc/(c^2-v^2) = (2d/c)\times 1/(1-v^2/c^2) = (2d/c)\times(1+v^2/c^2) \quad \textbf{(1)}$$

Briefly, the round-trip cross-stream time is calculated as

$$\text{Cross-stream round-trip time} = 2d/c\ /\ (c^2-v^2)^{1/2} = 2d/c\times(1-v^2/c^2)^{-1/2} = 2d/c\times(1+v^2/2c^2) \quad \textbf{(2)}$$

The difference of times in equation (1) and (2) show that there should be interference fringes when the two beams were re-combined. But the results showed virtually no interference fringes, indicating that speed of light was virtually the same in any direction, even when analyzed in various directions. This experiment proved that the speed of light is a constant regardless of the reference frame.

Michelson did many other independent experiments with the same purpose over many years. Results of all these experiments did not give any evidence for the existence of ether. Later on, in 1905, Einstein presented theory of relativity, which also accounted for these strange things without ever confirming the ether. Concepts that do not lead to observable manifestations cannot be incorporated into a physical theory and thus the perception of ether lost its physical meaning. So it was realized by the physicists that the ether idea was not necessary and never had been. As a consequence of the huge change in knowledge, the historic word ether is not used anymore, since it is an outdated thought based on classical physics. Today's equivalent of the ether is the quantum vacuum, finely explained by quantum physics.

Quantum Vacuum

Quantum physics is a physical theory which successfully describes the behavior of diverse effects up to date understanding. According to its modern perceptive, the vacuum state or the quantum vacuum is "by no means a simple empty space"[Lambrecht (2002)] and again: "it is a mistake to think of any physical vacuum as some absolutely empty void."[Ray (1991)]. The arrival of quantum physics has changed the concept of a vacuum. According to quantum physics, the vacuum state is not truly empty but instead contains momentary particles that pop into and out of existence [Schewe (1996), Dittrich (2000)]. Therefore physicists have come to realize that the vacuum is not just empty space and the absence of

things. Relativistic quantum physics makes a very clear distinction between what we would naturally understand to be an absolute void and what we experience as the vacuum of space. A number of experimental observations of the quantum physics clearly have shown that some physical phenomena like quantum fluctuations, Casimir effect, vacuum energy, vacuum polarization, etc. are explained by the fact that the vacuum space is not empty but has some nano-scale soft activities taking place in it. Some of such effects supportive for quantum vacuum are concisely deliberated.

Quantum Vacuum Fluctuations

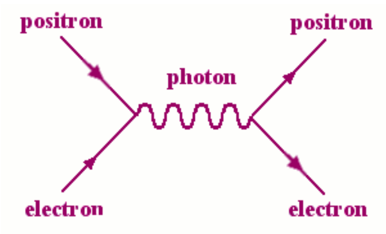

FIG. 2: QUANTUM FLUCTUATIONS OF VIRTUAL PARTICLES IN VACUUM SPACE.

It is observed that in quantum vacuum, particles and antiparticles can appear and then disappear after a short period of time within the constraints of the Heisenberg uncertainty principle ($\Delta E \Delta t \sim \hbar$). These particles appear in free space for short periods of time (Δt) depending upon their energy content (ΔE) and then disappear. So it can be said that the quantum vacuum is an ever changing collection of virtual particles which disappear after their short lifetime Δt to be replaced by new virtual particles that suffer the same fate [Daywitt (2009)]. Therefore the uncertainty principle implies that particles can come into existence for short periods of time even when there is not enough energy to create them. In fact, they are created from uncertainties in energy. It can be said that they briefly "borrow" the energy required for their creation, and then, a short time later, they pay the "debt" back and disappear again. So the quantum fluctuation is the temporary appearance of particles out of nothing. In view of the fact that these particles do not have a permanent existence, thus called virtual particles. The entire situation for electron positron pair creation and desertion is shown in figure-2 [Peter (1994)]. The existence of these particles has no mathematical fiction. Though they cannot be directly observed but the effects they create are observed and quite real. The assumption that they exist leads to predictions that have been confirmed by experiment to a high degree of accuracy [Leonhardt (2006)]. Consequently, the quantum vacuum that is the field where fundamental processes take place, is a pure summary of the quantum field theory [Figger (2002)] and is by no means an empty space where nothing ever happens. However, vacuum fluctuations are not some abstraction of a physicist's mind. They have observable consequences that can be directly visualized in experiments on a microscopic scale.

Properties of Quantum Vacuum Fluctuations

Phenomena like Casimir Force, Vacuum Energy, Vacuum Polarization, etc. can nicely be explained on the basis of quantum vacuum fluctuations.

1) *Casimir Force*

Casimir force is tiny attractive force acting between two closed parallel uncharged conducting plates. It is due to quantum vacuum fluctuation of the electromagnetic field. Modern physics undertakes that far from being empty, a vacuum is full of fluctuating electromagnetic waves that can never be completely eliminated. Therefore, if two mirrors are placed facing each other in a vacuum, some of the waves will fit between them, bouncing back and forth, while the longer waves will no longer fit, the result being that the total amount of energy in vacuum between the plates will be a bit less than the amount elsewhere in the vacuum. Thus, the mirrors will attract each other, just as two objects held together by a stretched spring will move together as the energy stored in the spring decreases. This effect is shown in figure-3 and more evidently in figure-4 [El-Genk (2006)]. It was first predicted in 1948 by Dutch physicist Hendrick Casimir [Casimir (1948)] and treated theoretically by Lifshitz in 1956 [Redhead (1993)]. Steve K. Lamoreaux, now at Los Alamos National Laboratory, who initially measured the tiny force in 1996 [Lamoreaux (1997), Schwinger (1993)]. There is now good agreement between theory and experimental measurements of this force. Mathematically, the Casimir force in vacuum space is as given in equation-3.

$$F = - \{(\pi^2 h c) / (240 d^4)\}A \quad \textbf{(3)}$$

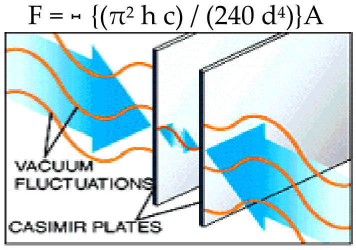

FIG. 3: CASIMIR EFFECT WITH PLATES AND VACUUM FLUCTUATIONS

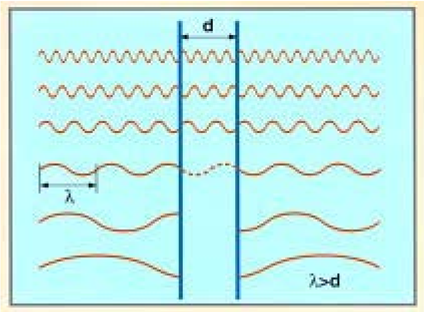

FIG. 4: CASIMIR EFFECT (D = PLATES SEPARATION, Λ = WAVELENGTH)

Where **h** is Plank's constant, **c** speed of light, **d** distance between the mirrors and **A** is area of the mirrors. The negative sign is indicates that the force is attractive. For two plane parallel plates of area A=1cm^3 separated by distance of d=1μm, the value of Casimir force ≈ 1.3×10^{-7}N [Boyer (1976), Manayev (1979)].

The Casimir force verses separation of plate of Cu and Au as shown in figure-5 [Lamoreaux (1997)].

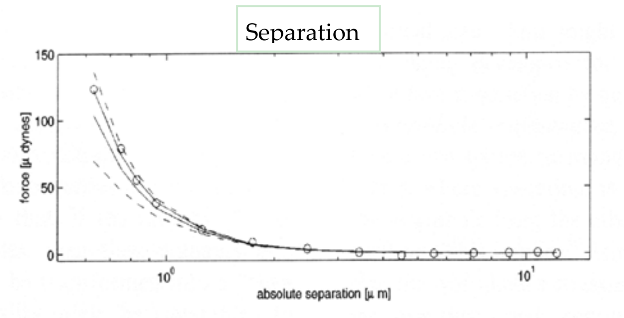

FIG. 5: CASIMIR FORCE VERSES PLATE SEPARATION: UPPER SOLID CURVE FOR CU AND LOWER SOLID CURVE FOR AU.

2) *Moving Mirrors Make Light from Nothing*

A group of scientists at Chalmers University of Technology have succeeded in creating light from vacuum space. In an innovative experiment, the scientists have managed to capture some of the photons that constantly appear and disappear in the vacuum space. This group claims to have coaxed sparks from the space of nothing [Wilson (2010)]. John Pendry, a theoretical physicist at Imperial College London said that if verified, the finding would be one of the most unusual experimental proofs of quantum mechanics in recent years and "a significant milestone". "It is a major development," says Federico Capasso, an experimental physicist at Harvard University in Cambridge, Massachusetts, who has worked on similar quantum effects. However, other scientists not directly connected with the group said that the result is impressive.

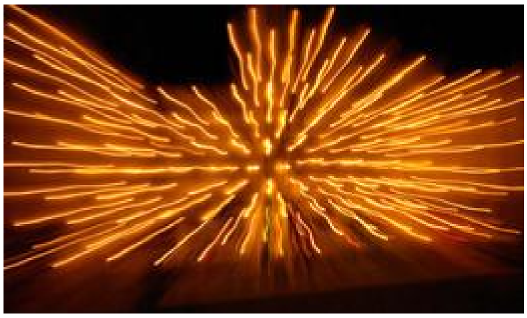

FIG. 6: A MOVING MIRROR CAN GENERATE LIGHT FROM VACUUM.

3) *Vacuum for Nano-science & Technology*

Nanotechnology is the technology of the century which is basic research and technology enlargement at the atomic, molecular or macromolecular levels, in the length scale of about 1-100 nanometer range. Vacuum of various ranges is really vital for some requirements of nano science and technology which enables this technology to succeed, from the initial research to commercialization and brings some benefits to life. Principally clean and controllable environments are key to success in this area, and vacuum is key to cleanliness and controllable process conditions. It can be indicated that vacuum science is the mother of all experimental sciences.

4) *Vacuum Energy*

Quantum vacuum is not with vacuity concept, but is filled up with newer and newer ideas. Quantum theory predicts, and experiments verify, that empty vacuum space contains an enormous residual background energy known as zero-point energy (ZPE). A modern idea of the quantum theory proposes that each point in space is filled up with energy. The low-energy electromagnetic waves, random in phase and amplitude, propagate in all possible directions [El-Genk (2006)]. Basically, vacuum energy is an underlying background energy that exists in space even when devoid of matter. It is deduced from the concept of virtual particles derived from the energy-time uncertainty principle as discussed earlier. Its effects, one like Casimir Effect has been measured with great accuracy [Mohideen (1998)], proving the best physical reality and significance of the quantum vacuum. This vacuum is the state of lowest energy with particles excitations like the excitations of guitar strings. The vacuum corresponds to silence with its nature like the un-played guitar which determines the particles spectrum like the possible sounds which can be produced with the guitar.

5) *Vacuum Polarization*

An added property of quantum vacuum fluctuations is vacuum polarization. If an electric charge for example, positive charge is placed in the vacuum space, it can polarize vacuum charge fluctuations because the positive charge attracts the electrons of the virtual electron-positron pairs, but repels the positrons. In this case, what is being polarized are the virtual electrons and positrons in the vacuum. Thus, on average, the barycentre of vacuum negative charges is closer to the charge than is the barycentre of vacuum positive charges. This results in a charge screening, the same as occurs for the charge in a dielectric. This polarization effect is shown in figure-7.

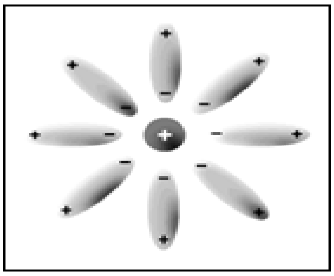

FIG. 7: VACUUM POLARIZATION.

Vacuum Applications

The matchless attribute of vacuum is that, it is used for multiple purposes and the most useful tool for numerous practices. In addition to its initial association with research in physics, the range of its applications has extended to important sectors of industrial activity, including pharmacy, food industry, metallurgy, mechanical, electrical, electronics, mechatronics, chemical engineering, surface engineering, etc. making an incalculable contribution to process effectiveness, efficiency and quality. Therefore, it is almost impossible to list all the areas in which vacuum that is now used and beyond the scope of this paper. Generally group wise presentation of various vacuum applications in diverse fields and different ranges (measured in Torr / Pascal) is shown in figure-8 [Akram (2012)].

Vacuum and its technology have been progressing by leaps and bounds. The preliminary status of vacuum cannot be compared with the existing one. Because in the 17th century, it was said by the Greeks that if vacuum is empty space filled with nothing, then "How can nothing be something". But now-a-days vacuum is not only the requirement of a particular process but is the crucial necessity for most of the advanced & sophisticated technologies. Consequently, it is now claimed that "vacuum is nothing but practically almost everything for the modern scientific technologies".

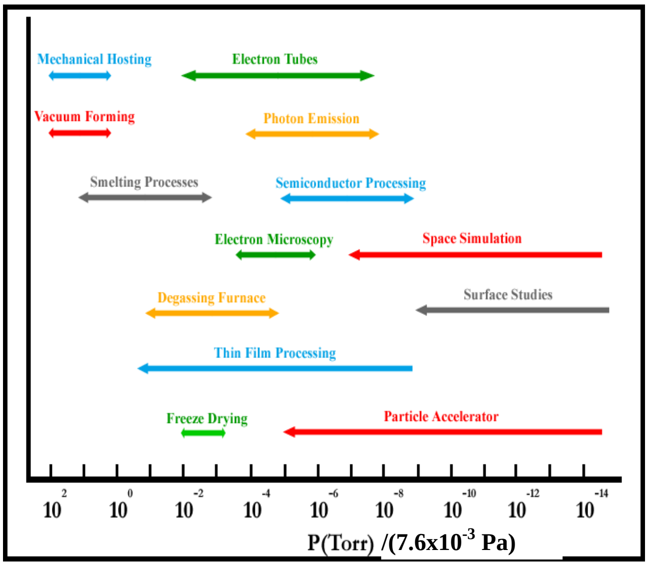

FIG. 8: VACUUM APPLICATIONS IN DIFFERENT VACUUM RANGES.

Conclusions

This review paper provided information that the concept of vacuum in modern physics is vitally different from that in old classical physics. The classical vacuum of quiet nothingness has been replaced by a quantum vacuum with fluctuations of measurable consequences. The experiments by the renowned scientists have first and foremost been found a turning point from classical to quantum physics which leads to the right course with careful experimentation and appropriate explanation. The new concept of vacuum has played an essential role in our understanding of the physical world. This review also briefly illustrated some phenomena's of the quantum vacuum: virtual fluctuations, Casimir force, vacuum energy, vacuum polarization, etc. Finally it can be thought that quantum vacuum physics is although the physics of nothing but the philosophy of everything. By the same token, it can also be said that as mathematics is the mother of all sciences, vacuum science is the mother of all experimental sciences.

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